

Sensitivity analysis for process parameters influencing weld quality in robotic GMA welding process

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Abstract

Generally, the quality of a weld joint is strongly influenced by process parameters during the welding process. In order to achieve high quality welds, mathematical models that can predict the bead geometry to accomplish the desired mechanical properties of the weldment should be developed. This paper focuses on development of mathematical models for the selection of process parameters and the prediction of bead geometry (bead width, bead height, and penetration) in robotic gas metal arc (GMA) welding. A sensitivity analysis has also been conducted and compared with the relative impact of three process parameters on bead geometry in order to verify the measurement errors on the values of the uncertainty in estimated parameters. The results obtained show that developed mathematical models can be applied to estimate the effectiveness of process parameters for a given bead geometry, and a change of process parameters affects the bead width and bead height more strongly than penetration relatively.

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1. Introduction

To get the desired quality welds, it is recently essential to have a complete control over the relevant process parameters to obtain the required bead geometry and which is based on capacity of weldment. However, mathematical model should be developed to make effective use of automated arc welding. Previous works on relationship between the process parameters and bead geometry in arc welding process can be grouped into two distinct areas: empirical methods based on studies of actual welding situations [1,2] and theoretical studies based on heat flow theory [3,4]. Despite the large number of attempts to analyse arc welding process, there is still the lack of a mathematical model that can predict bead geometry over a wide range of welding conditions.

Sensitivity analysis, a method to identify critical parameters and rank them by their order of importance, is paramount in model validation where attempts are made to compare the

calculated output to the measured data. This type of analysis can study which parameters must be most accurately measured, thus determining the input parameters exerting the most influence upon model outputs. It differs considerably from the usual approach of perturbing a process parameter of a known amount and evaluating the new results. Chuang and Hou [5] developed a sensitivity formulation for a planar frame parameter joint and support locations as design parameters. Also, Son and Kwak [6] established a sensitivity formulation for eigenvalues, including repeated eigenvalues, with respect to the change of boundary conditions. The tangential design velocity component was employed to present the change of boundary conditions. Recently, Choi et al. [7] proposed sensitivity analysis for laser surface treatment by the differentiation of the analytic solution with respect to the laser beam radius and beam scanning velocity. It is evident that the qualitative and quantitative effectiveness of the process parameters can be determined using sensitivity analysis.

In this paper, a methodology for understanding relationship between process parameters and bead geometry in gas

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metal arc (GMA) welding process is presented. The objective of this study is to find the optimal bead geometry in GMA welding process using mathematical models and to carry out a sensitivity analysis based on the developed empirical. Finally, the sensitivity results are compared and verified with the experimental results.

2. GMA welding process

The GMA welding process is a welding process, which yields coalescence of metals by heating with a welding arc between a continuous filler metal (consumable) electrode and the workpiece. The continuous wire electrode which is drawn from a reel by an automatic wire feeder, and then fed through the contact tip inside the welding torch, is melted by the internal resistive power and heat transferred from the welding arc. Heat is concentrated by the welding arc from the end of the melting electrode to molten weld pools and by the molten metal that is being transferred to weld pools.

The chosen factors for this study were welding voltage, welding speed and arc current, and the response were bead width, bead height and penetration. The process parameters and limits employed in this study are given in Table 1. All other parameters except these parameters under consideration were fixed. The experimental materials for development of mathematical equations were 200 mm × 75 mm × 12 mm mild steel AS 1204 plates adopting the bead-on-plate technique. The selection of the welding electrode wire was based principally upon matching the mechanical properties and physical characteristics of the base metal, weld size, and existing electrode inventory. Steel wire with diameters of 1.2 mm was employed as the welding consumables. Experimental test plates were located in the fixture jig by the robot controller and the required weld conditions were fed for the particular weld steps in the robot path. With welder and argon shield gas turned on, the robot was initialized and welding was executed.

This continued until the predetermined-experimental runs were completed. To measure the bead geometry, the transverse sections of each weld were cut using a power hacksaw from the mid-length position of welds, and the end faces were machined. Specimen end faces were polished and etched using a 2.5% nital solution to display bead dimensions. The experimental results were analyzed on the basis of relationship between process parameters and bead dimensions in GMA welding process.

Table 1
Process parameters and limits

Parameter	Limits
Welding voltage, V (V)	20, 25, 30
Welding speed, S (mm/min)	250, 330, 410
Arc current, I (A)	180, 260, 360

3. Results and discussion

3.1. Development of empirical models

Based on the results from the above factorial design, a curvilinear regression analysis was performed with the predictors that were found to be statistically significant against bead geometry. The commercial statistical package SAS [8] was utilized for all the multiple regression analyses in this research. The procedure employed for obtaining the predictive equation for bead geometry is shown below:

$$\text{bead width : } W = \frac{I^{0.3432} V^{0.6786}}{S^{0.4435} \times 10^{0.0176}} \quad (1)$$

$$\text{bead height : } H = \frac{I^{0.5443} \times 10^{1.1437}}{S^{0.2706} V^{1.1102}} \quad (2)$$

$$\text{penetration : } P = \frac{I^{1.5616}}{S^{0.4940} V^{0.1041} \times 10^{2.3835}} \quad (3)$$

The adequacy of the models and the significance of coefficients were tested by applying the analysis of variance technique and Student's t -test, respectively. Table 2 shows the standard error of estimates (S.E.E.), coefficients of multiple correlations (R), and coefficients of determination ($100R$) for the above models, respectively. It is evident that all models were adequate.

3.2. Sensitivity analysis of empirical equation for bead geometry

From the above resultant equation for estimation of bead geometry, the sensitivity equations are obtained by differentiation with respect to process parameters of interest such as arc current, welding voltage and welding speed that are explored here. To obtain the sensitivity equations for arc current, Eqs. (1)–(3) were differentiated with respect to arc current. The sensitivity equations are shown in Eqs. (4)–(6). They represent the sensitivity of bead width, height and penetration for arc current, respectively:

$$\frac{dW}{dI} = 0.3432I^{-0.6568} V^{0.6786} S^{-0.4435} \times 10^{-0.0176} \quad (4)$$

$$\frac{dH}{dI} = 0.5443I^{-0.4557} \times 10^{1.1437} S^{-0.2706} V^{-1.1102} \quad (5)$$

$$\frac{dP}{dI} = 1.5616I^{-0.5616} \times 10^{-2.3835} S^{-0.4940} V^{-0.1041} \quad (6)$$

Table 2
Analysis of variance tests for mathematical models for bead geometry

Bead geometry	S.E.E.	Coefficient of multiple relation	Coefficient of determination (%)
Bead width	0.0237	0.9645	93.02
Bead height	0.0659	0.8389	70.38
Penetration	0.0606	0.9513	90.56

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